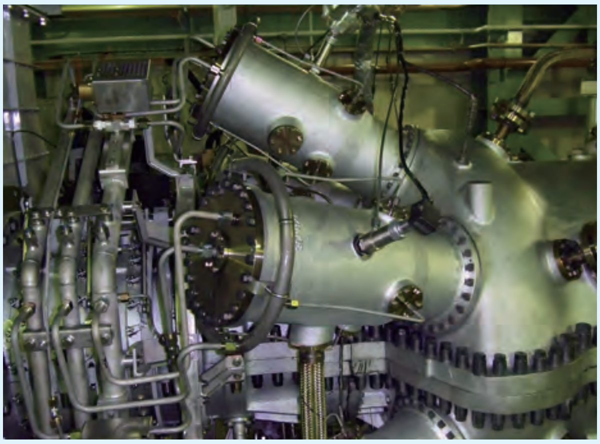
DLE combustion technology for enhancing environmental performance



With a product lineup of 0.7 to 30 MW class gas turbines, we are engaged in the development of combustors and working to commercialize them with the aim of assuring the world's top class emission performance in all models. This paper describes the development and demonstration of Kawasaki's DLE (Dry Low Emissions) combustion technologies.

Preface

As a result of rising environmental awareness, environmental regulations on gas turbine power generation systems have become stricter year by year, with this trend expected to continue. In response to stricter regulations, gas turbine manufacturers are accelerating the development of low-emission combustors. We have developed a lineup of various normal-use gas turbines of 0.7 to 30 MW class, for all of which we have developed and are commercializing low-emission combustors.

This paper presents some examples of our low-emission combustors and the world's highest level of guaranteed emission performance that they achieved.

1 Emissions of gas turbines and mechanisms to reduce them

Major emissions exhausted from gas turbine combustors are carbon dioxide (CO_2), nitrogen oxides (NOx), and carbon monoxide (CO). The reduction in CO_2 should be achieved through performance improvements of the gas turbine main body; this paper describes the reduction in NOx and CO through the improvement in combustion. The major causes of NOx emissions are categorized into the following three by generation mechanism: "thermal NOx" that is generated in the high-temperature range, "prompt NOx" that is generated on a fuel rich flame front, and "fuel NOx" that is generated by the oxidation of nitrogen contents in fuel molecules. For the use of gas turbine generator sets, "thermal NOx" governs the NOx emissions, and the key is how to reduce them (hereinafter, "NOx" refers to thermal NOx). On the other hand, CO is an intermediate product occurring as a result of the combustion of hydrocarbon fuel on the verge of being further oxidized into CO_2, and can be decreased by raising the flame temperature or lengthening the staying time in a high temperature range.

The production of NOx increases rapidly as the flame temperature rises. On the contrary, CO increases suddenly as the flame temperature falls. For this reason, if a high temperature range exists even partially as shown in Fig. 1,

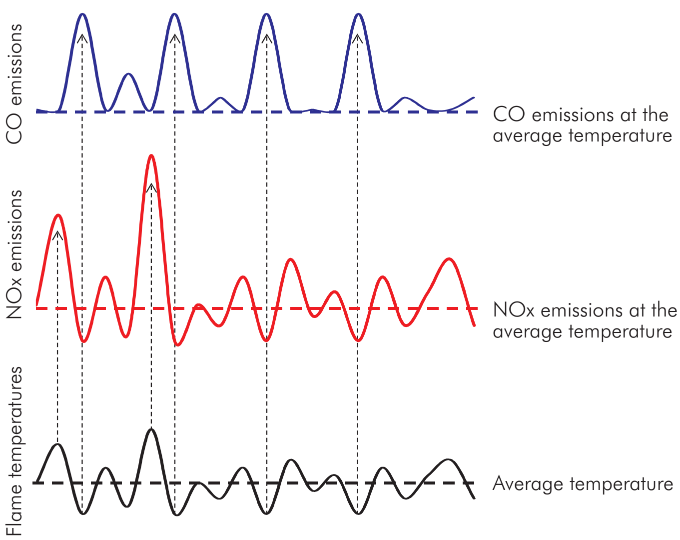


Fig. 1 Relationship between NOx and CO formations and flame temperature distribution

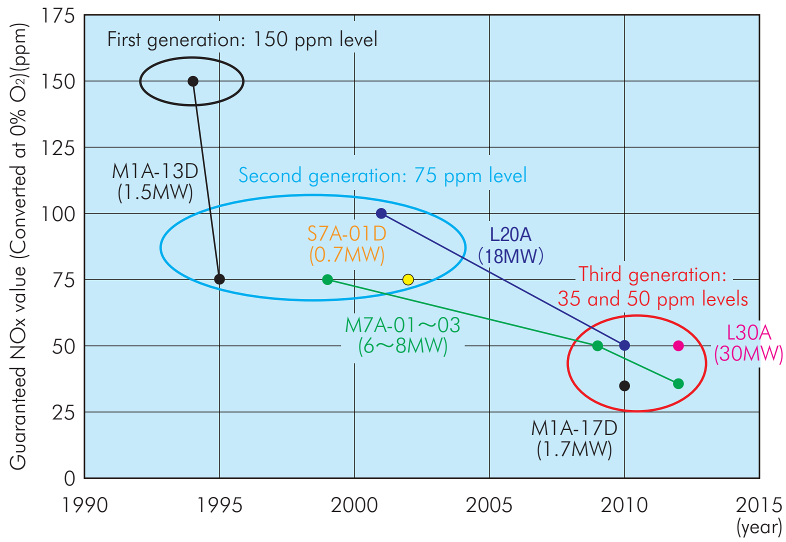


Fig. 2 History of Kawasaki DLE combustion technologies

a large quantity of NOx is produced in that range while a large quantity of CO is produced in a low temperature range, if any.

To reduce NOx, it is important to lower the average flame temperature and homogenize the fuel concentration distribution so as to smooth out the flame temperature on the one hand and to keep a balance with CO emissions on the other.

2 Development of low-emission combustors by Kawasaki

(1) History of our DLE combustion technology

With gas turbine combustors, a technique of water or steam injection into a diffusion combustor was originally adopted to reduce NOx. In the 1990s, however, Dry Low Emissions (DLE) combustion technology that reduced NOx without water or steam injection was developed. We, too, developed and started commercialization of DLE combustion technology in the mid 1990s[1]. We have since continued efforts to extend this technology to all models of normal-use gas turbines and lower the guaranteed NOx level. Fig. 2 shows a history of our DLE combustion technology. The first generation DLE combustion technology guaranteed NOx emissions on a 150 ppm (converted at 0% O_2) level, with the guarantee lowered to the 75 ppm level by the second generation. The present DLE combustion technology is the third generation, and we guarantee a 50 or 35 ppm value, the world's top level.

(2) Features of Kawasaki's DLE combustors

Lean premixed combustion system DLE combustors adopted by gas turbine manufacturers are capable of controlling NOx emission by controlling the flame temperature uniformly and at a low value by first mixing air and fuel, and then firing the mixture. In this system, on the other hand, the range in which fuel burns stably is limited, and, therefore, the operating range is limited from the viewpoint of compatibility with CO exhaust. With our DLE combustor, the operating range where low NOx emission is compatible with combustion stability can be extended if the combustion state of the main burner, in which lean premixed combustion is carried out, is maintained in a low NOx and stable state, and if the variation in fuel consumption by engine output is smoothed out by the amount of combustion of the supplemental burner.

Figure 3 shows a schematic diagram of our DLE combustor (M7A-03, third generation DLE combustor). Our

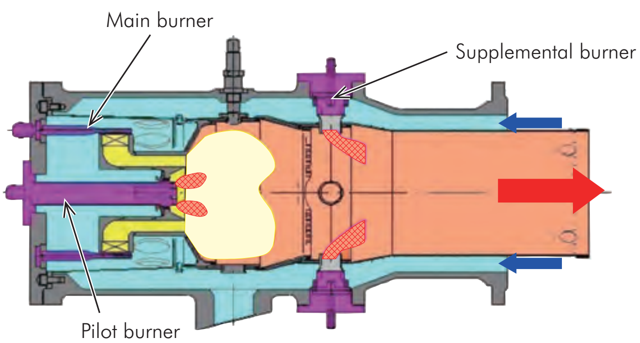


Fig. 3 Schematic diagram of third-generation DLE combustor for M7A-03

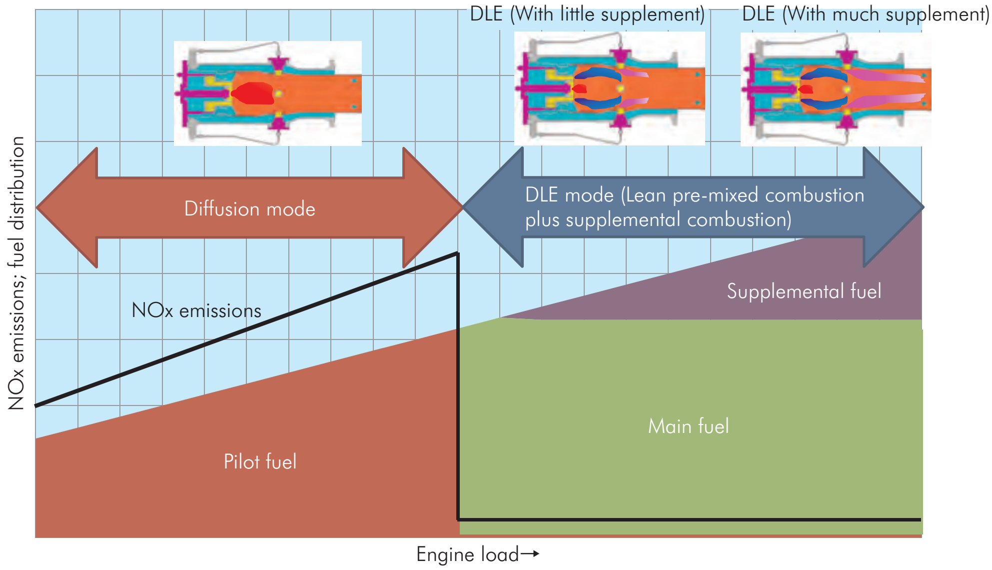


Fig. 4 Conceptual diagram of burner control and NOx emission using Kawasaki DLE combustion technology

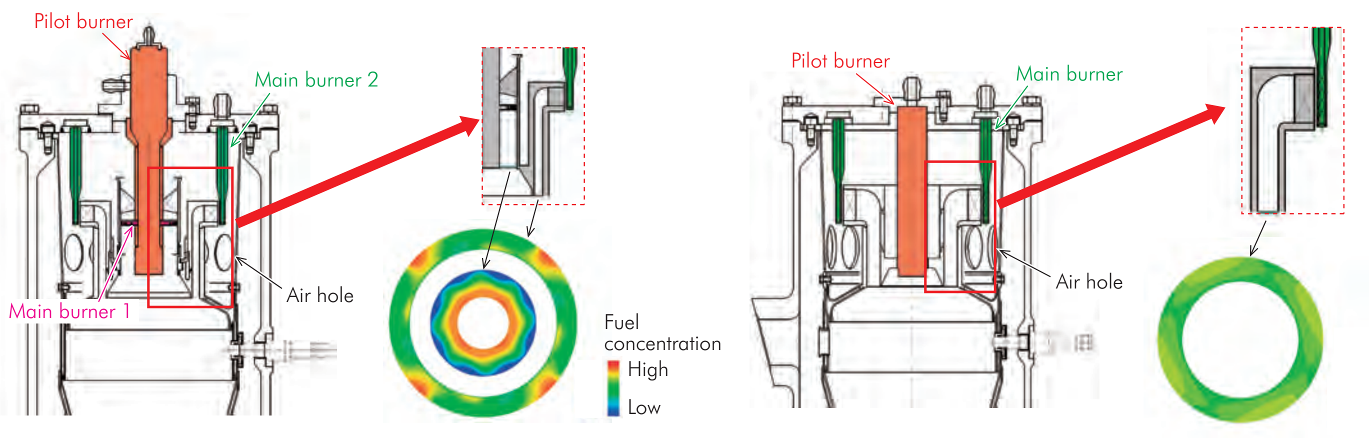
DLE combustor is composed of a three-burner system that includes a pilot burner to be used in starting or during low loading, other than the above mentioned capabilities. Fig. 4 shows a conceptual diagram of burner control (fuel distribution control) and NOx emission.

(3) Development of DLE combustors

In developing DLE combustors, shapes are adjusted by computational fluid dynamics (CFD) analysis, flow measurement, rig combustion tests, and similar means, and shapes are confirmed by engine tests. If problems are found, the same process is repeated, with the optimization work being continued until the final mass-production shape is obtained.

(i) CFD analysis

To cut back NOx, it is necessary to make the fuel concentration distribution uniform. Fig. 5 shows examples from CFD-based analyses of air-fuel mixing carried out to improve the concentration distribution. Fig.5 (a) shows a second generation DLE combustor and Fig. 5 (b) a third



(a) Second generation DLE combustor

(b) Third generation DLE combustor

Fig. 5 Fuel concentration distribution at outlet of main burner

(a) Overall view

(b) Combustor outlet

Fig. 6 Acryl combustor for PIV measurement

generation DLE combustor. The illustration shown on the left of each figure is the cross-section of the entire main burner and pilot burner, while the illustration on the right shows the result of CFD analysis on the concentration distribution and the positions at which the concentration distribution was assessed. The illustrations show that, in the third generation DLE combustor, the optimization of the position at which the fuel is injected into the air flowing into the main burner results in a more uniform concentration distribution.

(ii) Flow measurement

As an example of a method for measuring the flow inside a combustor, Particle Image Velocimetry (PIV) is presented here. PIV is a technique in which fine particles are added to a fluid and the velocity field of the fluid is investigated by measuring the velocity of the particles with laser light. Fig. 6 shows an acryl combustor used in PIV measurement. In this case, measurement is made from the side while laser light is radiated from the outlet side of the combustor. Fig. 7 shows an image obtained by letting oil mist flow (fine particles) in the combustor and visualizing the flow with the Mie-Streuung scattered light from the oil mist, while Fig. 8 is a velocity vector diagram obtained by PIV measurement of the area inside the red dotted-line frame.

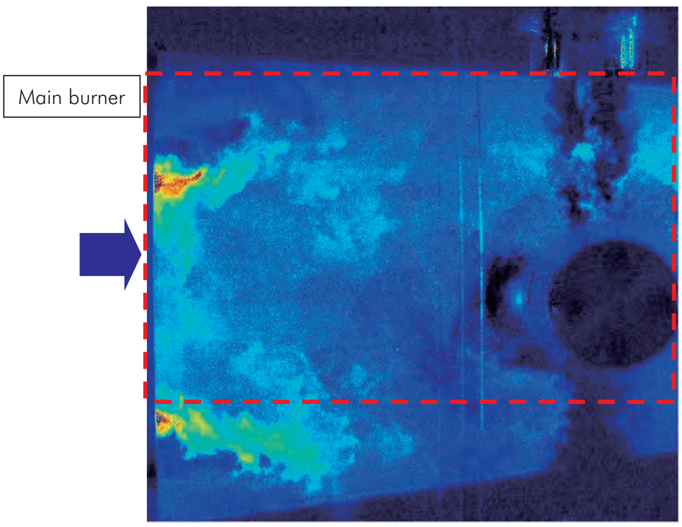


Fig. 7 Image of internal flow of combustor visualized with oil mist

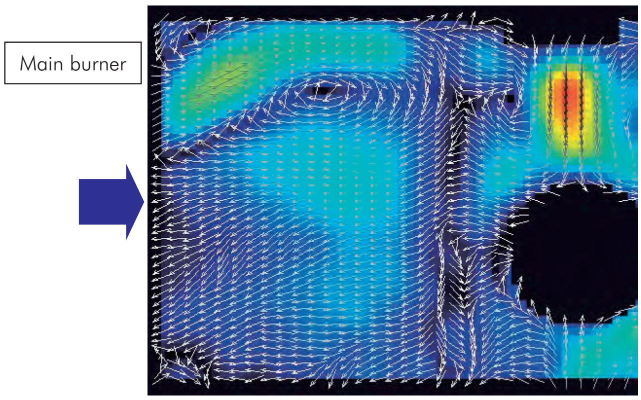


Fig. 8 Result of PIV measurement (Velocity vector)

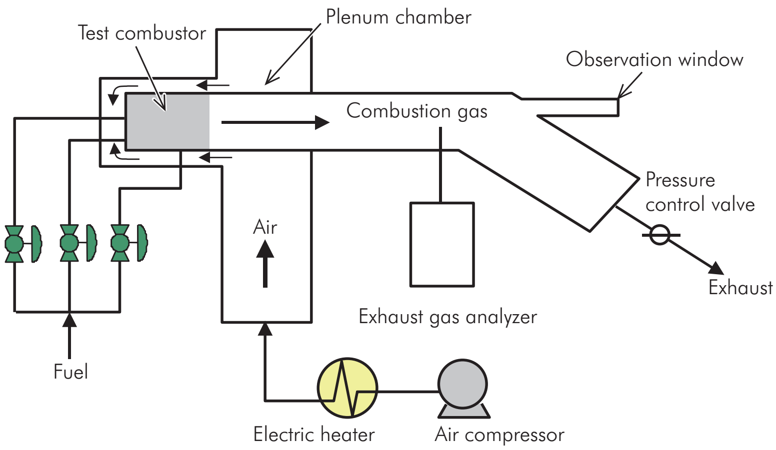


Fig. 9 System diagram of combustion test facility

(iii) Rig combustion test
We have installed five combustion test facilities for gas turbine combustors, using different facilities for different purposes. Fig. 9 shows the system diagram of a typical combustion facility. To simulate the conditions at the inlet of the combustor of an engine, air is compressed, with its temperature raised, to specified conditions and then fed to the combustor. With its flow rate controlled in a different system, the fuel is fed into the combustor. High-temperature combustion gas generated in the combustor is cooled and then discharged into the atmosphere.

In the rig combustion test, combustion performance characteristics such as ignition performance and emission, and liner wall temperature, which is associated with the durability of the combustor, are measured and used as a basis for improving design prior to engine tests. During the test, the condition of the flame is observed constantly through an observation window provided downstream of the combustor. Fig. 10 shows an image of a flame photographed from downstream of the combustor. Observation of the flame is an extremely important means for understanding the state of combustion. The rig combustion test allows fuel conditions and air conditions to be varied independently of each other, which in turn allows data to be obtained under a wide range of conditions. For example, carrying out an engine test under intake conditions of – 20°C or + 50°C is difficult. But, it is possible in a rig test to simulate the conditions at the combustor inlet.

(iv) Engine test
Figure 11 shows the result of an engine test using our M7A-03 third generation DLE combustor. The illustration shows that a reduction in NOx is compatible with a reduction in CO in a load factor range of 50 to 100%.

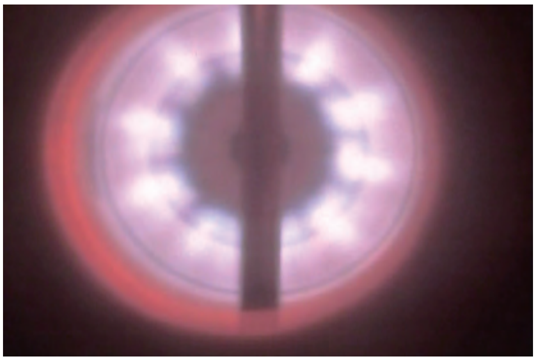


Fig. 10 Image of flame as observed from downstream of combustor

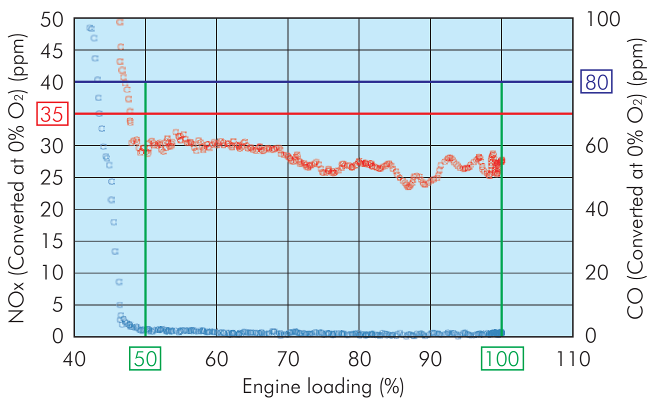


Fig. 11 NOx and CO emissions from engine

Fig. 12 Power generation plant (PUC80D) with M7A-03

3 Operation of a state-of-the-art third generation DLE combustion system

A demonstration facility was installed and has been operating on the premises of our works to serve the final stage of development work. As an example of installation of the third generation DLE combustion system, the power generation plant (PUC80D) with M7A-03 operated at our Akashi Works is shown in Fig.12. This combustor is operated with an NOx concentration level of 35 ppm or less (converted at 0% O_2).

Concluding remarks

Today is characterized by stricter environmental regulations and higher awareness of environmental preservation. We will continue developing combustion technology that can materialize environmental performance of the world's highest level and offer it to the market.

Reference

1) S. Kajita, et al.: "Advanced Development of a Second-Generation Dry Low-NOx Combustor for 1.5 MW Gas Turbine," ASME 96-GT-49, 1996.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